

WIND-INDUCED LOADS OVER DOUBLE CANTILEVER BRIDGES UNDER CONSTRUCTION

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Abstract. *Within the last century the interest in wind-induced loads over civil engineering structures has become more and more important, the reason being that the development of new construction techniques and materials has allowed engineers and architects to design new structures far from the traditional concepts, and in many cases wind actions over these singular structures are not included in the existing codes of practice. In this paper the wind-induced static loads over bridges constructed by the double cantilever method during erection stages are considered. The aerodynamic load over a double cantilever bridge under a yawing-angled wind produces a yawing (torsional) moment on the bridge deck, which can lead to undesirable rotation of the deck about the supporting pier. The effects of the wind yaw angle and the length of the deck are analysed. The wind action caused by the presence of sliding concrete forms at the ends of the deck is also studied.*

1 INTRODUCTION

As a result of the introduction of new construction techniques and materials in civil engineering, designers must face designs that are not covered by the applicable codes for calculating the wind actions. In these cases the support of wind tunnel testing is recommended for the estimation of the wind loads. This could be the case of bridges constructed by the double cantilever method where wind forces could cause the rotation of the deck. The double cantilever bridges are formed in the erection stages by the deck, which is progressively constructed at both extremes by sliding concrete forms, and a pier which supports the deck at the middle point (see figure 1). At this configuration a yawing moment over the deck can be induced by the wind due either to:

- 1) a yaw angle of the incident wind with respect to the bridge deck,
- 2) wind gusts.

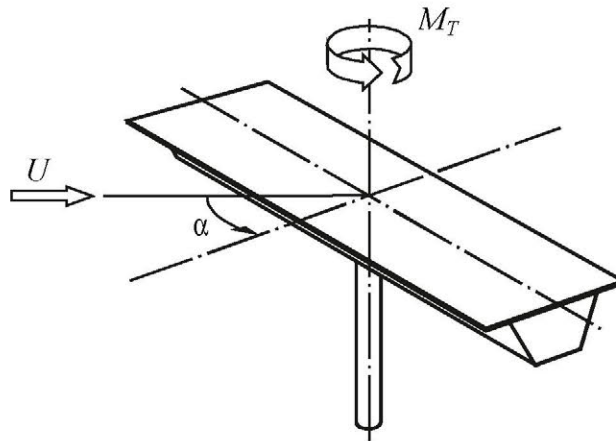


Fig. 1. Double cantilever bridge under a non-zero wind yaw angle, α . Wind velocity, U , and yawing moment over the bridge pier, M_T , are also indicated.

As far as we know this problem has not been analysed in depth in the literature, and only a few references dealing with wind loads on double cantilever bridges have been found. Dyrbye and Hansen¹ propose a method to calculate the maximum yawing moment produced by the wind on a double cantilever bridge (the method takes also into account the dynamic effects of the wind over the bridge when its yaw angle is zero). Mendes and Branco² apply the same method to calculate the wind forces on a bridge over Douro river (Portugal), including the effect of cantilevers bending. Most of the papers dealing with wind action over bridges are oriented to the dynamic interaction between the structure and the wind turbulence, and it is hard to find information on forces acting on such structures, even considering uniform, smooth flow. Available information in codes of practice is scarce and limited to very particular configurations. For instance, in *Eurocódigo I*³ a method to estimate the static wind loads on the bridge when the wind is either perpendicular or parallel to the bridge deck is only presented.

In this paper the wind action over a double cantilever bridge at different yaw angles is experimentally analysed by measuring in a wind tunnel the mean moment, M_T , of a bridge deck model when subjected to a uniform flow.

2 EXPERIMENTAL PROCEDURES

To perform the experiments on the yawing moment due to the wind acting on the deck of a bridge under construction, a set of three models of a very simplified bridge deck has been built-up. The deck section, as sketched in figure 2, consists of a platform $a = 0.24$ m in width and $a/48$ in thickness, supported by a beam $a/3$ in height, with its width varying linearly from $a/3$ at the beam bottom till $a/2$ at the beam top. Therefore, the area of the cross-section of this bridge-deck model is $A = 23(a/12)^2$, which has been used in the following as the reference area to make dimensionless the measured magnitudes. Three bridge-deck lengths, l_i , have been considered, $l_1 = a$, $l_2 = 2a$, and $l_3 = 3a$. During all tests the bridge-deck is supported by a vertical rod, $a/5$ in diameter and $5a/4$ in height, which in turn is anchored to a six-component strain-gauge balance.

To simulate the sliding concrete forms of the deck bridge three different end-plate sets, whose dimensions are also defined in figure 2, have been considered. In case A the end-plates width is $a/24$ and in cases B and C the end-plates width is $a/48$. The different bridge deck configurations considered in the measurement of the yawing moment have been twelve: three bridge-deck lengths and for each of these four different endings (no plates, and the three types of plates sketched in figure 2).

During the experiments the yawing moment on the bridge deck at different yaw angles ranging from 0° to 180° has been measured (see figure 1), together with the rolling moment, the pitching moment and the three components of the aerodynamic force acting on the deck (although these last five components of the aerodynamic load are out of the scope of this work and the results are not presented in the following).

Measurements have been carried out in the A9 Wind Tunnel of IDR/UPM, whose test chamber is 1.5 m in width and 1.8 m in height. As already stated the bridge-deck model under testing is anchored to a six-component strain-gauge balance model EX114.45-200 by Midi Capteurs, S.A., which is mounted on a rotating platform NEWPORT RV120-PP-HL. This rotating platform allows the angular positioning of the model with respect to the wind tunnel axis (yaw angle) with enough accuracy, better than $\pm 1^\circ$.

The balance and the rotating platform are placed inside a chamber located under the wind-tunnel floor. This chamber is connected to the wind-tunnel test chamber through a circular hole whose diameter is slightly larger than the diameter of the vertical rod which simulates the supporting pier of the bridge deck. With this arrangement only the vertical rod and the bridge

deck (plus the end plates, if any) are subjected to the air flow. Therefore, since the yawing moment due to the circular rod is practically negligible (formally this moment must be zero because of the symmetry of the rod with respect to the incident wind), the yawing moment measured by the balance is only due to the aerodynamic loads acting on the bridge deck.

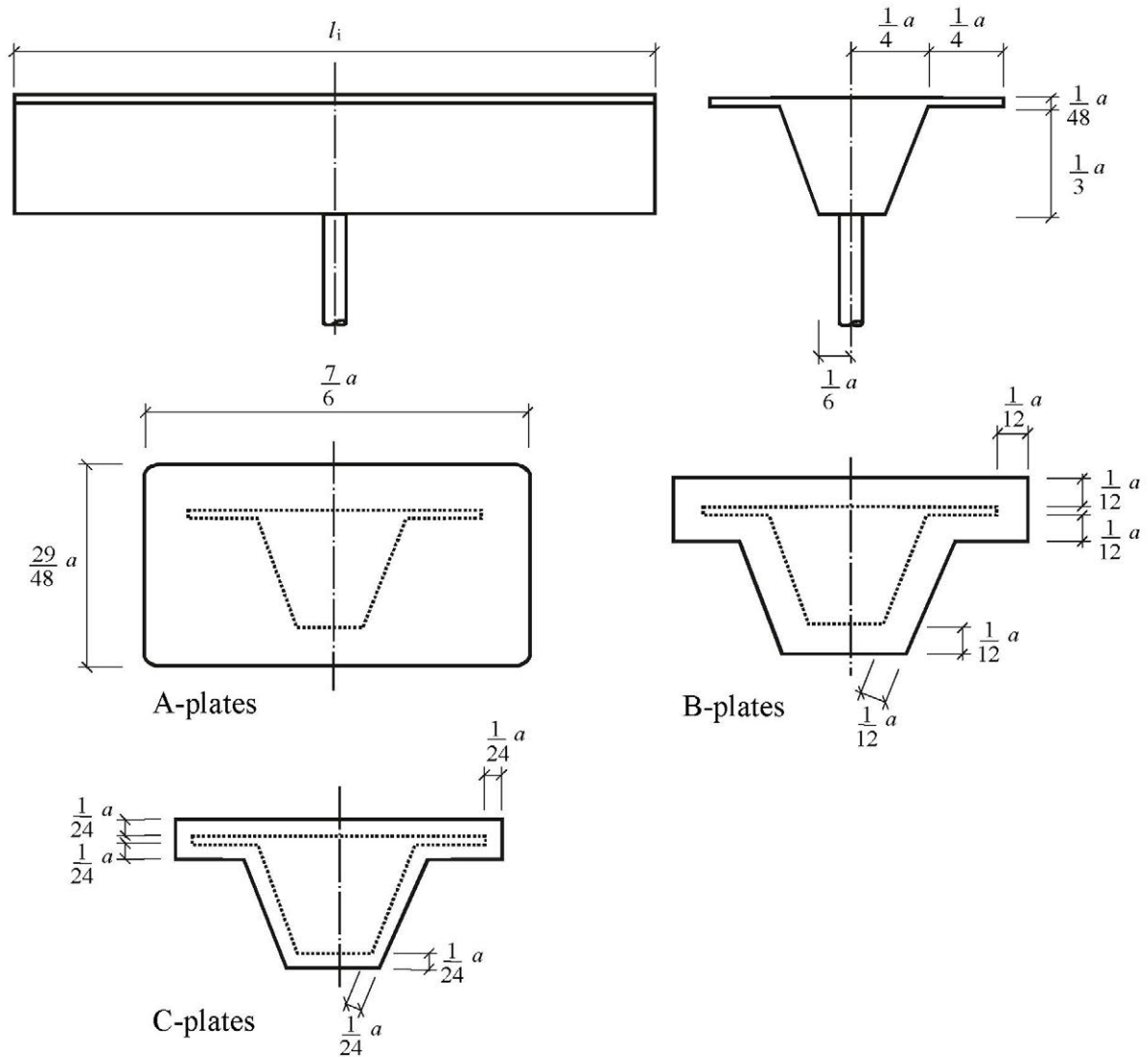


Fig.2. Testing model used in the wind experiments.

The dynamic pressure inside the test chamber is measured directly by a calibrated Pitot tube Air Flow 048 connected to a pressure transducer Schaewitz Lucas P3061-2 WG. Experiments have been performed in a low turbulence, uniform, air stream (the turbulence intensity being some 2.5 %), the wind speed being at least $20 \text{ m}\cdot\text{s}^{-1}$, which provides a

Reynolds number, based on the characteristic length a , higher than 3×10^5 . It must be pointed out that even in the worst case (a l_3 length bridge deck at 0° yaw angle), the frontal area of the model, including the rod that simulates the supporting column, is smaller than 4 % of the wind-tunnel cross-section, so that no provisions for blockage-correction of the measured results have been considered. No atmospheric boundary layer simulation was performed, since in this problem atmospheric boundary layer effects are negligible, provided the bridge deck is high enough over the ground, and the bridge deck is not too thick (so that the wind speed behaves as uniform close to the bridge deck).

Experimental procedure is as follows: once the model (supporting rod, bridge deck and end plates) is fixed to the six-component balance, the rotating platform is set to the initial yaw angle. Then the wind tunnel is switched-on and when steady conditions are reached inside the wind-tunnel test chamber the measurement process starts. At each one of the selected values of the yaw angle electric signals coming from the balance are digitised and stored in a PC for further analysis; once a given set of data is stored the operator switches-on the rotating platform that rotates till a new yaw angle is reached, and then the new set of values generated by the balance are stored.

3 RESULTS AND DISCUSSION

The measured yawing moment over the bridge deck, M_T , has been made dimensionless using:

$$c_M = \frac{M_T}{qAl_i}, \quad (1)$$

where c_M is the dimensionless yawing moment coefficient, q is the dynamic pressure ($q = \frac{1}{2} \rho U^2$, being ρ and U the density and the velocity of the air stream, respectively), A is the area of the cross-section of the bridge deck, and l_i its length.

The dependence of the yawing-moment coefficient on the yaw angle for the different configurations tested is shown in figure 3. In these plots white-square symbols represent results corresponding to the bridge without any end plates, whereas the black-square, white-circle and black-circle symbols correspond respectively to results of the bridge with A-plates, B-plates and C-plates allocated at both extremes of the deck.

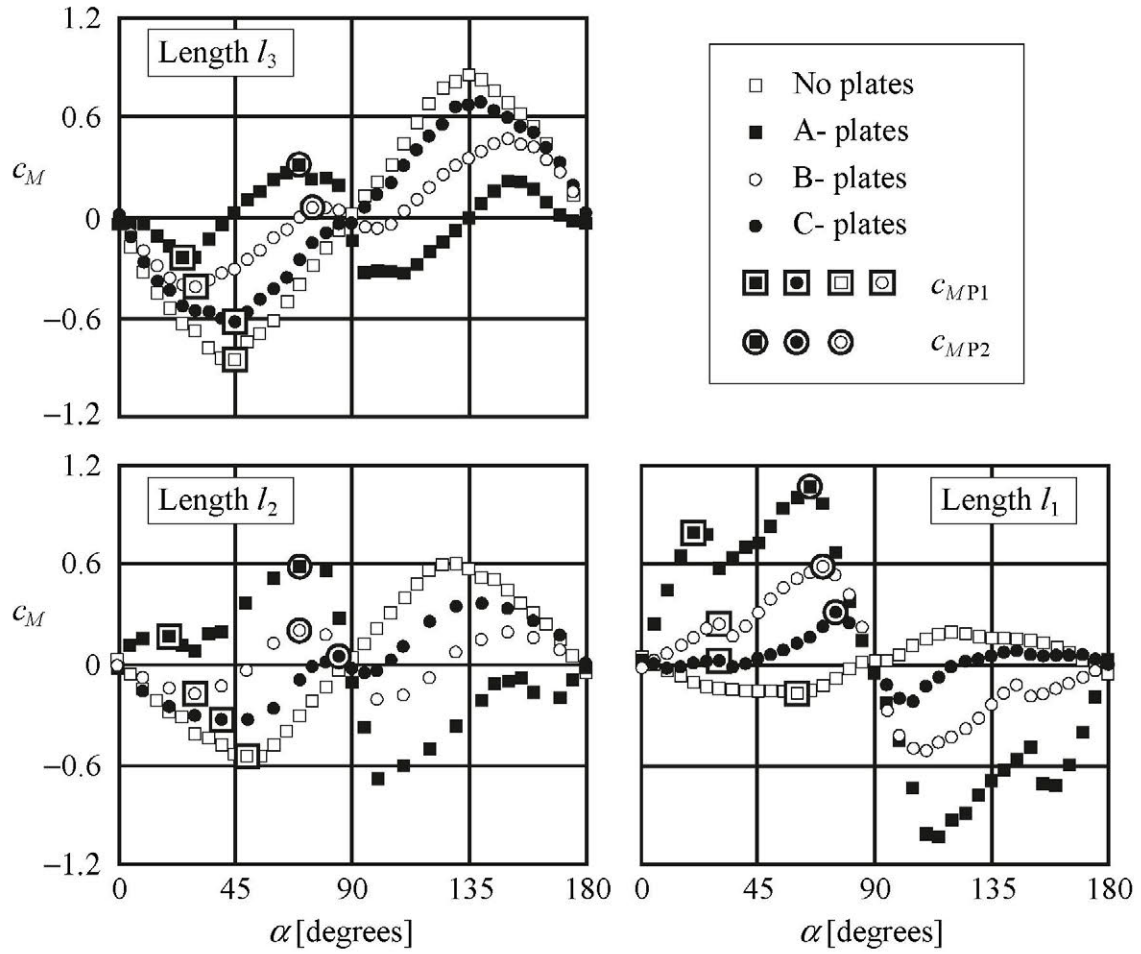


Fig. 3. Variation of yawing moment coefficients, c_M , measured on the three bridge decks as function of the wind yaw angle, α . White-square symbols represent results corresponding to bridge decks with no plates at the ends. Black-square, white-circle and black-circle symbols represent results corresponding to bridge decks with A-plates, B-plates and C-plates, respectively. The peaks of the coefficient, c_{MP1} and c_{MP2} , are framed in squares and circles respectively.

As it was expected, the behaviour of the aerodynamic load is anti-symmetrical about the yaw angle, $\alpha = \pi/2$, that is $c_M(\pi/2 - \alpha) = -c_M(\pi/2 + \alpha)$. Due to this reason, from now on all explanations will only refer to yaw angles ranging from $\alpha = 0^\circ$ to $\alpha = 90^\circ$. With no plates placed at the ends of the bridge deck, the measured yawing moment coefficient presents a minimum near round $\alpha = 45^\circ$ for the three decks tested. This peak, denoted as c_{MP1} (framed in squares in the figure 3), decreases and slightly displaces towards $\alpha = 90^\circ$ as the deck length is diminished. Also for all decks tested, the presence of the plates at the deck ends adds an extra yawing moment of an opposite sign from the one measured with no plates. This contribution displaces the position of the peak c_{MP1} towards $\alpha = 0^\circ$.

In all cases tested with plates at the deck ends, the behaviour of the yawing moment coefficient as function of the yaw angle presents a second peak, denoted as c_{MP2} (framed in circles in the figure 3). This second peak appears in the interval from $\alpha = 60^\circ$ to $\alpha = 90^\circ$ and diminishes with the length of the deck. It must be remarked that for a fixed deck length, the peak c_{MP2} tends to disappear and displaces from $\alpha = 60^\circ$ towards $\alpha = 90^\circ$ as the area of the plates is decreased.

In figure 4 the peaks c_{MP1} and c_{MP2} are shown as function of the length of the bridge. As it can be observed, the peak c_{MP2} tends to zero as the deck length is increased. Concerning the peak c_{MP1} , a linear tendency with the deck length is also observed. This linear tendency implies a quadratic tendency of the yawing moment with this parameter, as it was made dimensionless with the length of the bridge, l_i , to compute the yawing moment coefficient, see equation (1).

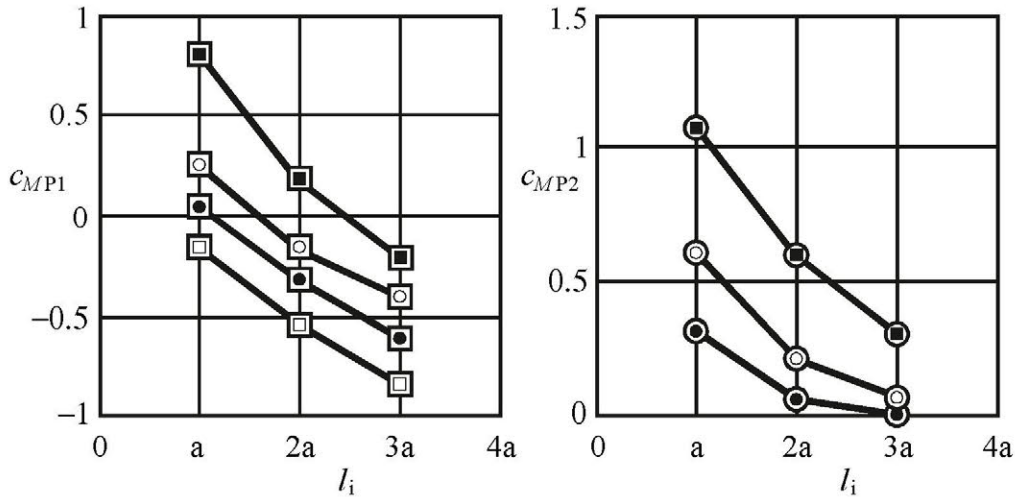


Fig. 4. Variation of the yawing moment coefficient peaks, c_{MP1} and c_{MP2} , with the length of the bridge, l_i . Black-square, white-circle and black-circle symbols correspond to bridge decks with A-plates, B-plates and C-plates respectively. White-square symbols correspond to bridge decks with no plates.

The mentioned influence of the plates allocated at the ends of the deck on the yawing moment is explained as follows:

- 1) Near $\alpha = 0^\circ$ yaw angle plates behave as thin plates under small angles of attack. So lift and drag forces appear on the plates modifying the yawing moment over the bridge in comparison with the no plates case. See figure 5a.
- 2) For yaw angles near $\alpha = 90^\circ$, not only extra forces are generated on the plates. The pressure distribution is now rather different from the no-plates case. As it is indicated in figure 5b, the position of the stagnation point is modified and now it is positioned on the most upstream plate and even more, just behind this plate a low-pressure zone appears as consequence of the wake formed. Also the presence of the downstream plate

modifies the pressure distribution over the bridge because a new high-pressure zone appears now just upstream this plate.

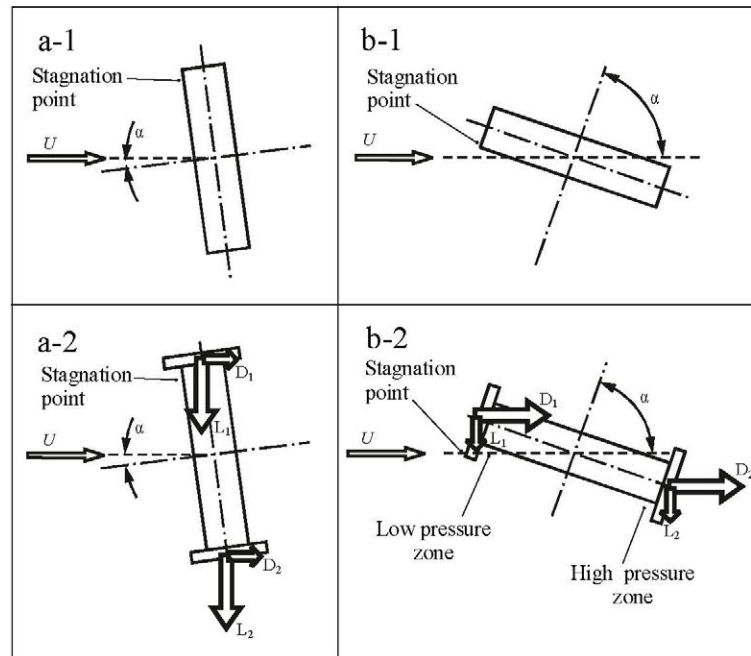


Fig. 5. Sketch of the aerodynamic forces that appear on the bridge deck with plates.

Summarising, the following conclusions are obtained:

- 1) In a double cantilever bridge under construction the maximum yawing moment over the deck caused by yaw angled wind grows quadratically with the bridge length. To prevent possible accidents this effect must be foreseen.
- 2) This maximum yawing moment is somehow alleviated by the presence of sliding concrete forms or other construction elements disposed at the ends of the deck.

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